

LabVIEW Strain Gage Sensor Integration

(This manual is extensively based on material in Reference 1)

Introduction

Different types of sensors are commonly used in real life engineering applications to acquire real time data. Strain gages are one of these examples which are used to measure the strain in structures. Output signal from these sensors is the form of voltage or current signals which is calibrated against some known values of input.

These output signals (Volt /Amp) are weak signals and mostly of the order of 10^{-3} or even less. Direct measurement of these signals makes it difficult to draw meaningful conclusions. Addition of noise makes the task more cumbersome. In order to ease the task, these signals are amplified and filtered before measurement. For any available equipment with some specified least count, amplification of signal increases the sensitivity of the system. Filters are used to remove the un-wanted portion of signal (noise), generated by surrounding or the circuit itself.

In this laboratory, you will build an analog circuit that will enable you to measure the voltage output of a strain gage mounted on a cantilever beam (metal beam) to measure its deflection. You will then add a non-inverting op-amp to amplify the voltage output from your circuit and an analog low-pass filter to remove voltage fluctuations caused by high frequency noise. As an additional exercise, you will modify the given LabVIEW program to configure another channel for simultaneous measurement of two input signals.

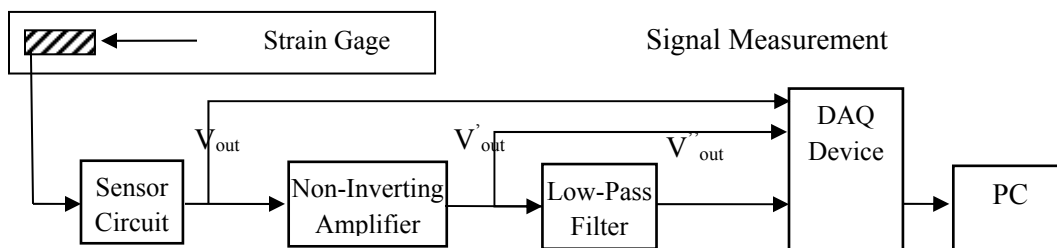


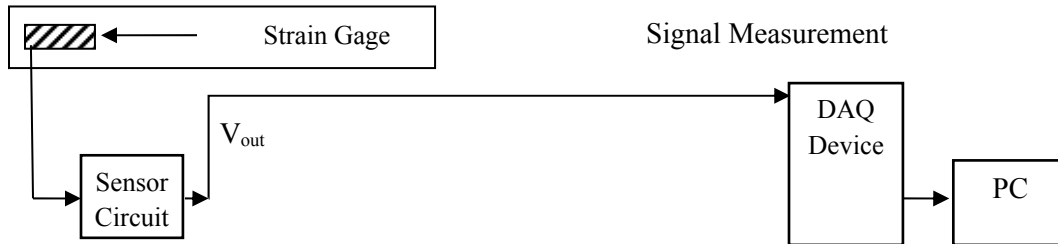
Figure 1: Strain Gage Sensor System

Note:

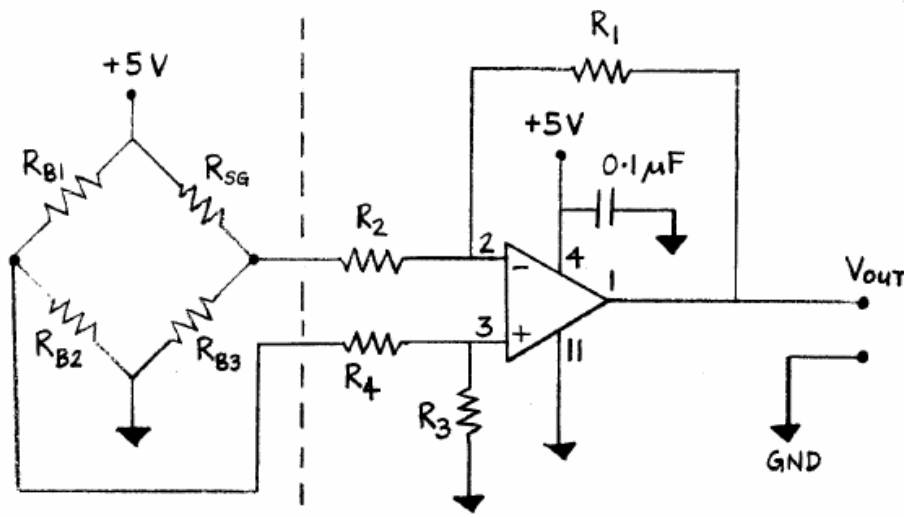
- Evaluate gain A_v in Experiment 2 for Combination 3 before coming to class and include in your prelab.
- Estimate the cutoff frequency ω_0 of the filter both in rad/sec and Hz in Experiment 3 before coming to class and include in your prelab.
- Evaluate the transfer function between the input voltage V'_out and V''_out as shown in Figure 8 Experiment 3 before coming to class and include in your prelab.

Experiment #1: Building an analog circuit to obtain deflection measurements using a strain gage

In this experiment, you will build an analog circuit for using a 120- Ω strain gage to measure the voltage output of the strain gage on the metal beam. You will then observe the voltage output from your deflection sensor circuit using LabVIEW and the program “voltage.vi”. The strain gage, which includes two wire leads, has already been attached (glued) to a bendable beam.

**Figure 2: Strain Sensor**

1. Build the analog circuit shown in Figure 3 on an electronic breadboard¹. Remember to use red wire for positive power connections and black wire for ground connections. Since the strain gage has a resistance of (approximately) $R_{SG} = 120\Omega$, the resistors² on the remaining three arms of the Wheatstone Bridge should be matched such that $R_{B1} = R_{B2} = R_{B3} = 120\Omega$. Make sure you measure with the multimeter all the components and verify their values before using them in the circuit.

**Figure 3: Wheatstone Bridge****Op-Amp Circuit**

¹ see the breadboard connectivity Figure 12 at the end of this manual

² the R_B resistors are known as “bridge completion resistors”

The voltage output from the Wheatstone bridge is amplified by the NTE 987 (Quad op-amp)³ operational amplifier, shown on the right side of the dotted line in Figure 3. The NTE 987 contains four op-amps with identical capabilities (see Figure 4); any one of these can be used. The pin numbering in Figure 3 is according to op-amp number 1. Care must be taken while connecting the amplifier in the circuit. Reversing the power (V^+ connection 4) and ground (V^- connection 11) connections will heat up the amplifier and ultimately burn it.

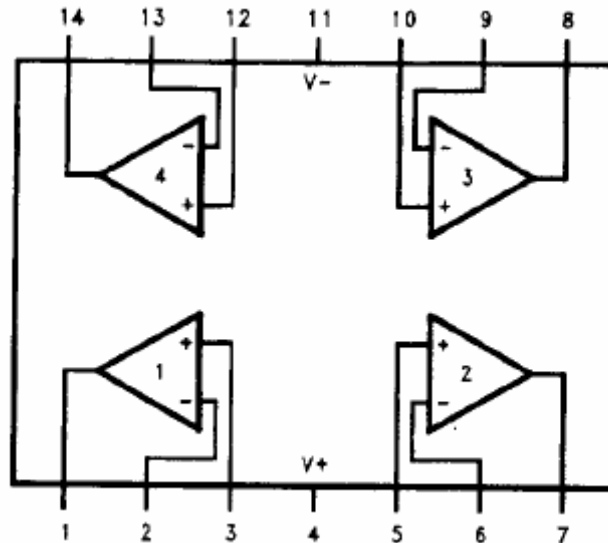


Figure 4: NTE 987 Connection Diagram

Choose the op-amp resistors such that $R_1 = R_3 = 1 \text{ M}\Omega$ and $R_2 = R_4 = 100 \text{ k}\Omega$. Then, the voltage gain A_V of your op-amp circuit will be $A_V = R_1 / R_2 = 10$. Power up the op-amp and Wheatstone bridge to 5 Volts (measure this with a multimeter).

- Run the Voltage VI on the desktop of your PC. Connect the voltage output V_{OUT} and ground (GND) from your circuit to AI0 (analog input channel 0, white cable). Connect the black cable to the ground on your breadboard. See Figure 14 in the appendix for the wiring connections to the USB DAQ device.
- Take the beam and deflect it upward and downward. Observe the resulting voltage output V_{OUT} on the graph. The vertical scale of your graphical output will be automatically adjusted according to the range of input signal. V_{OUT} is the sum of two voltage components given by $V_{OUT} = V_{DC} + V_{defl}$

where V_{DC} is a roughly constant DC bias voltage and it depends upon the unbalance of Wheatstone bridge when the beam is not deflected. V_{defl} is the meaningful component because it depends on the deflection of the metal beam. Theoretically, when the beam is not deflected, and if all four resistors in the Wheatstone bridge are perfectly matched (equal to one another), the DC bias V_{DC} should be zero. In practice, however, the resistors are not exactly matched, so the circuit may have a nonzero DC bias even when the beam is not deflected.

- Deflect the beam with your hand and observe the sensitivity of system. The whole deflection of approximately one inch could be divided into 3 or 4 steps on output. If the system is unable to sense the deflection of less than 1/4 inch of beam deflection we can conclude that system sensitivity or least count is 1/4 inch.

5. In order to make the system more sensitive there are two ways.

- a. Use a more sensitive DAQ system
- b. Amplify the signal

You will use option (b) and amplify the V_{out} available from the first circuit in the next experiment.

Once you are successful in obtaining a meaningful signal inform the GTAs or the instructor. You will be given a short introduction to LabVIEW by setting up your own virtual instrument (VI) to acquire all the three signals for this set of experiments. This step will also address Experiment 4.

Experiment #2: Amplifying voltage output from strain gage circuit

In this experiment, you will amplify the voltage output from your strain gage circuit using a non-inverting operational amplifier.

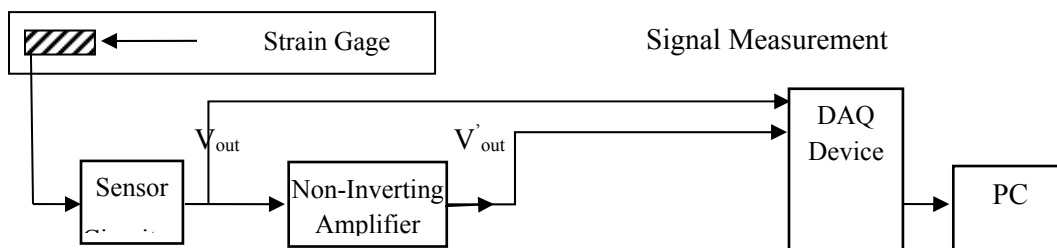


Figure 5: Strain Gage with Voltage Amplification

One way to amplify the voltage output is to increase the resistance of both R_1 and R_3 or to decrease the resistance of both R_2 and R_4 . We will assume that the circuit you built in Experiment # 1 cannot be modified, which is usually the case with many circuit boards you may encounter in industrial applications. Instead, amplification of the existing voltage output V_{OUT} could be performed quite easily using a non-inverting operational amplifier.

- Add the circuit shown in Figure 6 to the circuit you built in Experiment #1. Use op-amp number three (pin numbers 8, 9, and 10) on the NTE 987 (Figure 4). Choose the source resistor R_S and the feedback resistor R_F according to one of the combinations below (ask GTA which combination to use)

Combination 1: $R_S = 10 \text{ k}\Omega$ $R_F = 150 \text{ k}\Omega$

Combination 2: $R_S = 20 \text{ k}\Omega$ $R_F = 100 \text{ k}\Omega$

Combination 3: $R_S = 10 \text{ k}\Omega$ $R_F = 75 \text{ k}\Omega$

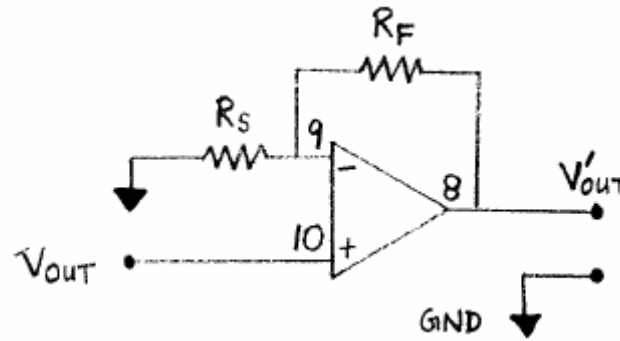


Figure 6: Amplification Circuit

The voltage gain A_V for the non-inverting op-amp is given by $A_V = \frac{V'_{out}}{V_{out}} = 1 + \frac{R_F}{R_S}$. Evaluate A_V for

Combination 3 before coming to class and include in your prelab.

- Connect the amplified voltage output V'_{OUT} and ground (GND) from your circuit to the DAQ card. In this step you will need to connect the amplified signal (V'_{out}) to AI1 (analog input channel 1, red cable). Leave the black cable connected to the ground on your breadboard. See Figure 14 in the appendix for the wiring connections to the USB DAQ device. This will allow you to observe both the initial or raw signal and the amplified signal on the same scope.
- Deflect the beam upward and downward. Verify that the amplified voltage output V'_{OUT} on the *LabVIEW* graph is similar to what you observed at the end of Experiment #1. While deflecting the beam, observe the increased sensitivity of the system. Theoretically, the system should be x -times more sensitive to deflection than before, i.e. if the least count of the previous system was $1/3$ or $1/4$ inch, it should be $1/x$ times the previous value, where x is the amplification value.
- Evaluate the amplification ratio and compare with the expected one based on the resistors used.
- Observe that you also amplify the noise of the measured voltage signal which is an undesirable effect. The effect of the noise could be reduced by developing a filter, either a digital or an analog filter. In the next step, you will add an analog filter to minimize this noise.

Experiment #3: Adding an analog low-pass filter to the strain gage circuit

In this experiment, you will add an analog low-pass filter to your circuit to reduce the voltage fluctuations caused by high-frequency noise.

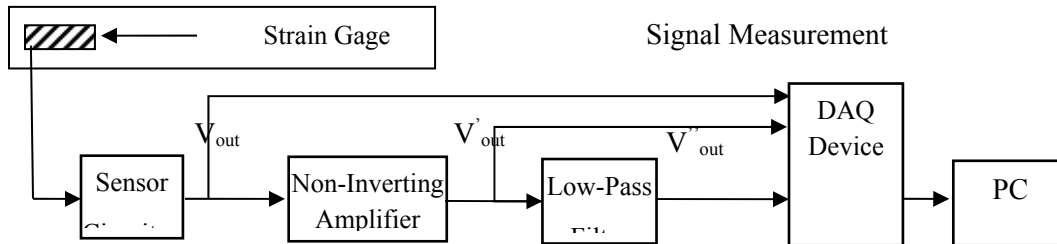


Figure 7: Strain Gage Sensor with Voltage Amplification and Analog Low-Pass Filter

Add the RC low-pass filter shown in Figure 8 to the circuit you built in Experiment #2. Choose the resistor R_{LP} and the capacitor C_{LP} such that $R_{LP} = 100 \text{ k}\Omega$ and $C_{LP} = 0.1 \text{ }\mu\text{F}$. Estimate the cutoff frequency ω_0 of the filter if $\omega_0 = 1/RC$ both in rad/sec and Hz.

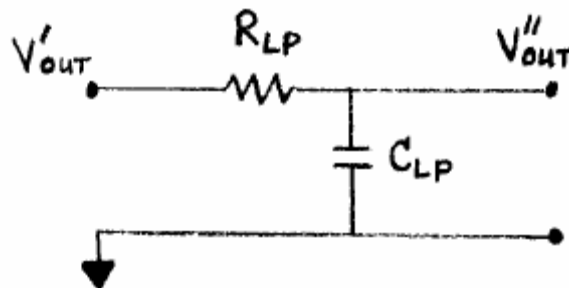


Figure 8: RLC Low-Pass Filter

1. Connect the filtered voltage output V''_{OUT} and ground (GND) from your circuit to AI2 (analog input channel 2, yellow cable). Leave the black cable connected to the ground on your breadboard. See Figure 14 in the appendix for the wiring connections to the USB DAQ device. This will allow you to observe all the signals on the same scope.
2. Deflect the beam upward and downward. The screen will show all the signals from the circuit. Observe the difference between the unfiltered signal (V'_{out}) and filtered one (V''_{out}).
3. At home you are required to find the transfer function $V''_{out}(s)/V'_{out}(s)$ and evaluate the DC gain based on the resistor and capacitor and compare with the experimentally obtained results.
4. You can experiment with different resistors to modify the cutoff frequency and observe the effects on the filtered signal.

Experiment #4: Adding another channel to the USB DAQ setup to acquire two or more signals simultaneously

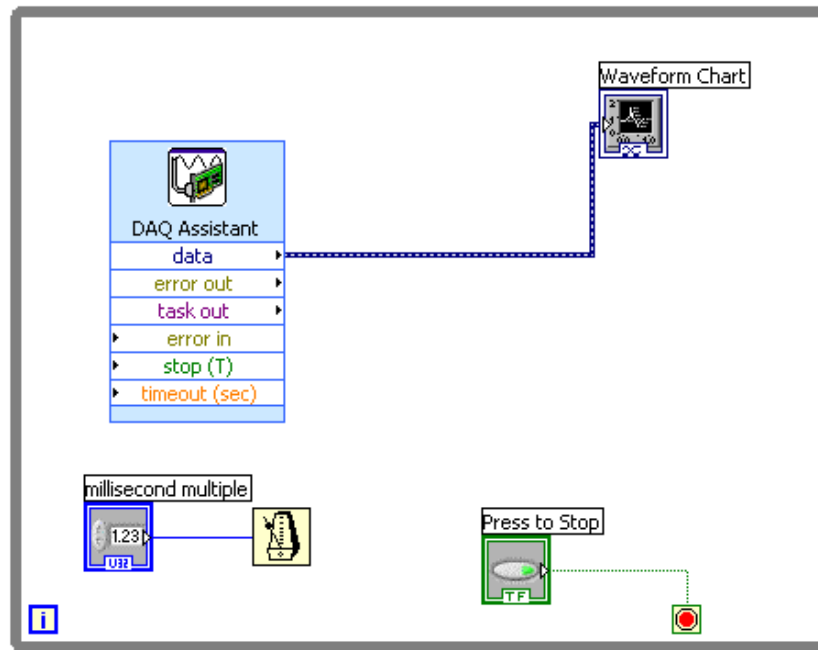


Figure 9: Block Diagram of VI

1. Open the block diagram of this VI by using the “Window” pull down menu. The first option is “Show Block Diagram”. It will appear as in Figure 9
2. Double clicking the “DAQ Assistant” in this VI will open “DAQ Assistant” dialogue box.
3. At the top select “Add Channels” and select voltage from the available selections. “Add channel to the Task” menu will appear. It will show the connected DAQ devices with the available channel for voltage measurement. “ai0” is already used. Select the desired channel from the remaining ones based on the hardware connectivity and click “ok”.
4. Change the settings appropriately based on the range of values you will be acquiring, the termination characteristics, the number of samples and the acquisition rate. For this experiment, set the Max value to “5”, Min to “0”, RSE termination, 1000 samples, 1 kHz rate and N-samples. Also, the connection diagram to the DAQ device could be accessed at the bottom of the dialogue box. Then, you click on the OK button to accept these settings and add the channel to the VI.
5. Go to the “Front Panel” and Run the VI. Graph will display two signals instead of one. When connected, the difference between filtered and un-filtered signal can be observed. The effect of the low-pass filter should be clear. The voltage fluctuations due to noise should be significantly less after filtering.

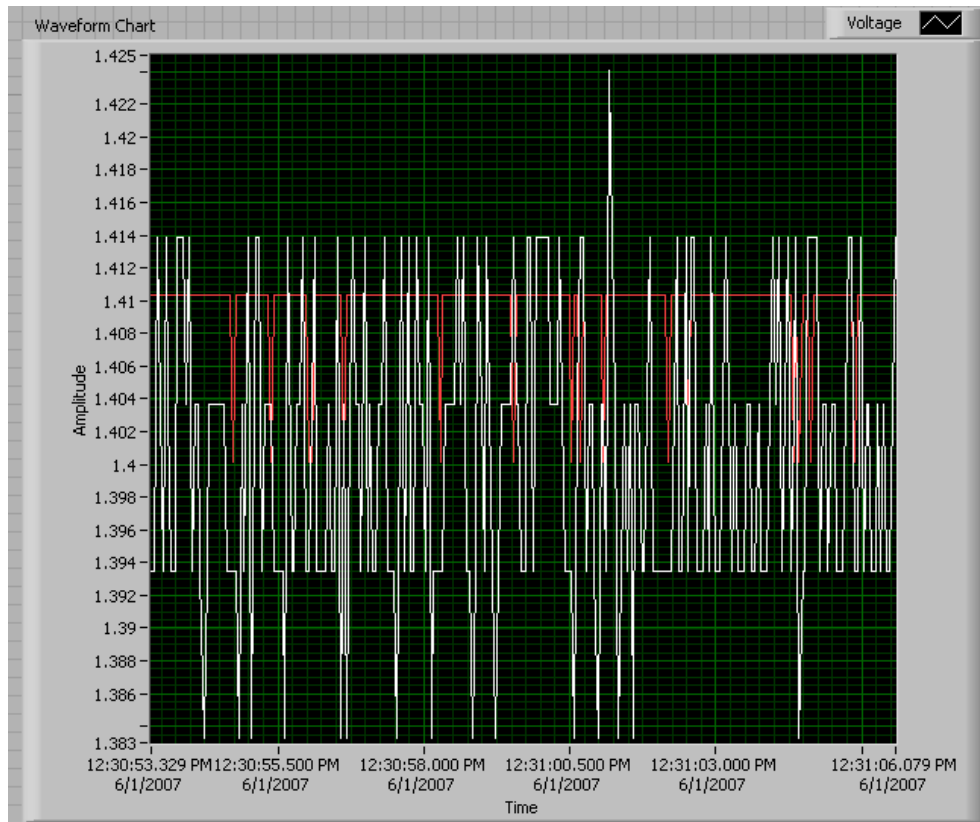


Figure 10: Second Channel Added to the DAQ System

References

1. Lab Manual "Strain Gage Sensors" Department of Mechanical and Environmental Engineering. University of California Santa Barbra.
2. LabVIEW User Manual

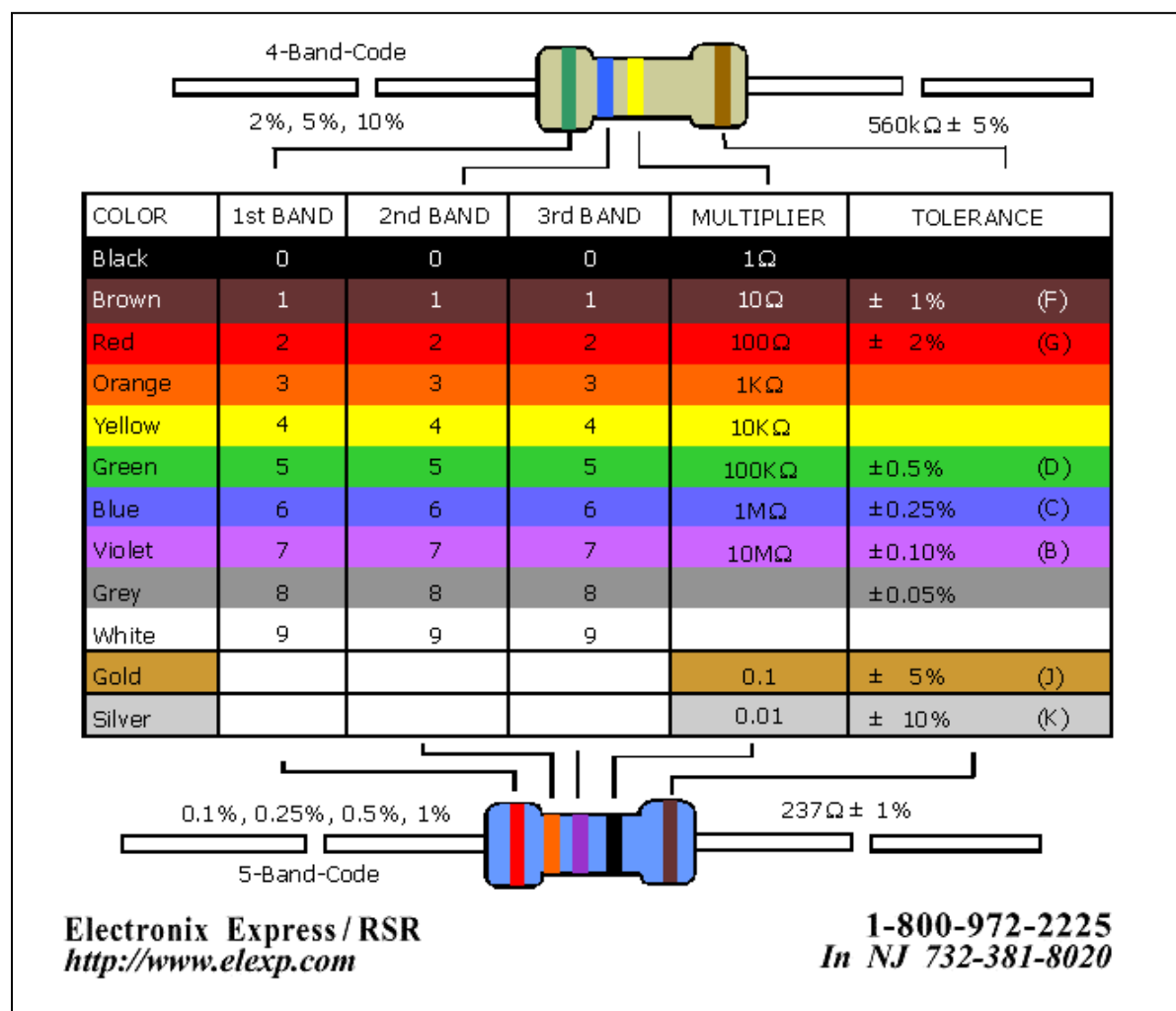


Figure 11: Resistor Color Coding (Courtesy: Electronix Express)

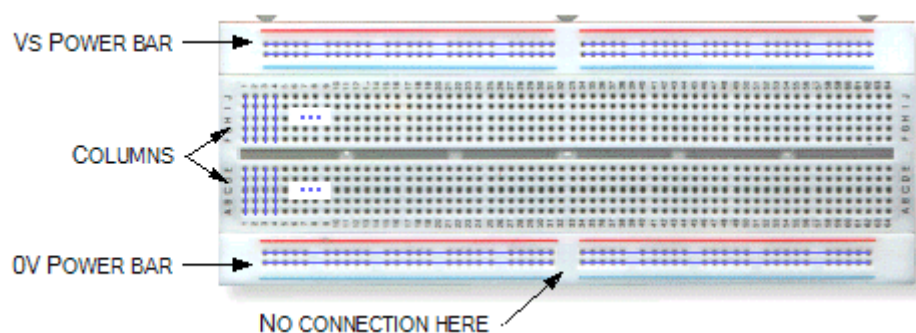
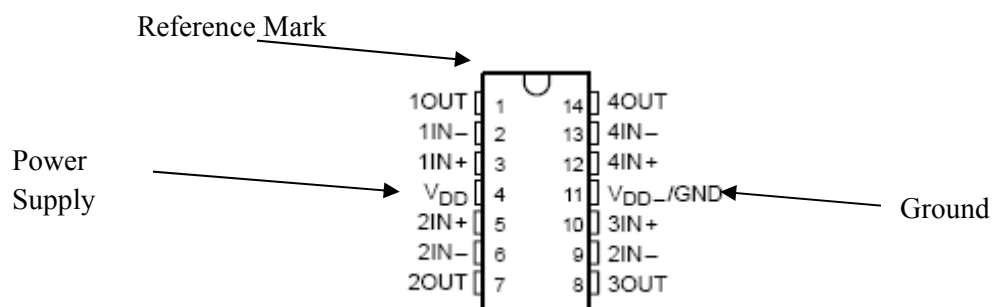


Figure 12: Breadboard Electrical Connectivity

**Figure 13:** NTE 987 Top View

GND	1	17	P0.0
AI 0/AI 0+	2	18	P0.1
AI 4/AI 0-	3	19	P0.2
GND	4	20	P0.3
AI 1/AI 1+	5	21	P0.4
AI 5/AI 1-	6	22	P0.5
GND	7	23	P0.6
AI 2/AI 2+	8	24	P0.7
AI 6/AI 2-	9	25	P1.0
GND	10	26	P1.1
AI 3/AI 3+	11	27	P1.2
AI 7/AI 3-	12	28	P1.3
GND	13	29	PFI 0
AO 0	14	30	+2.5 V
AO 1	15	31	+5 V
GND	16	32	GND

Figure 14: NI USB 6008 DAQ Pinouts

Note the labels for Analog and Digital signals on the actual hardware device.